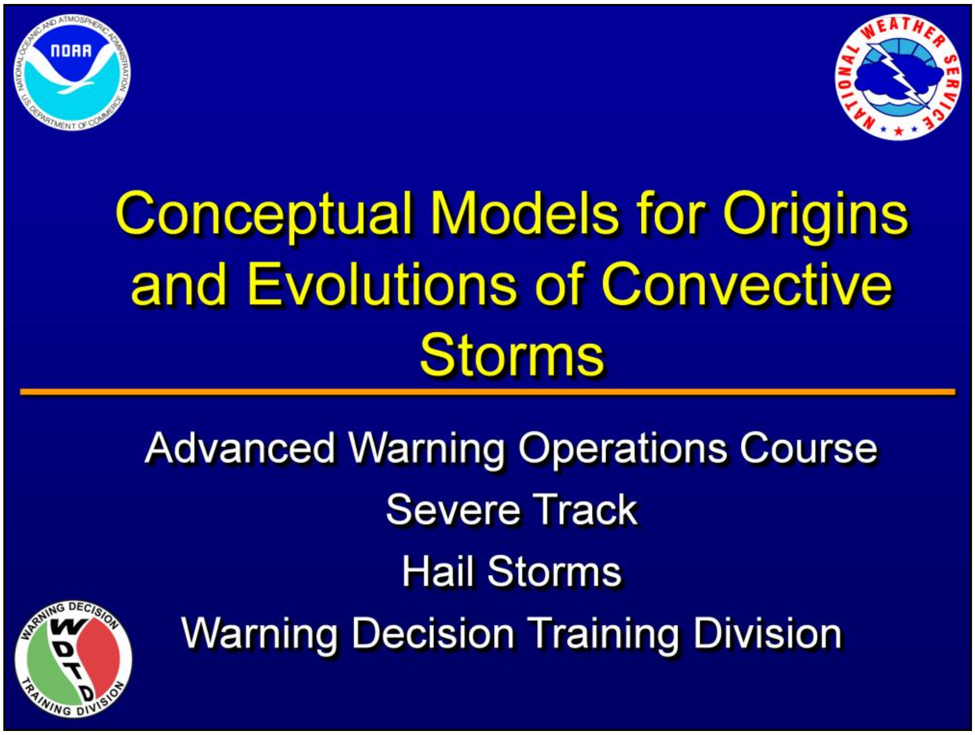

Welcome to the Advanced Warning Operations Course Severe Track lesson on hail storms.


Image 2
Tab 1
Tab 2
Tab 3
Course Completion Info
Tabs - 4 Tabs (Including Introduction)
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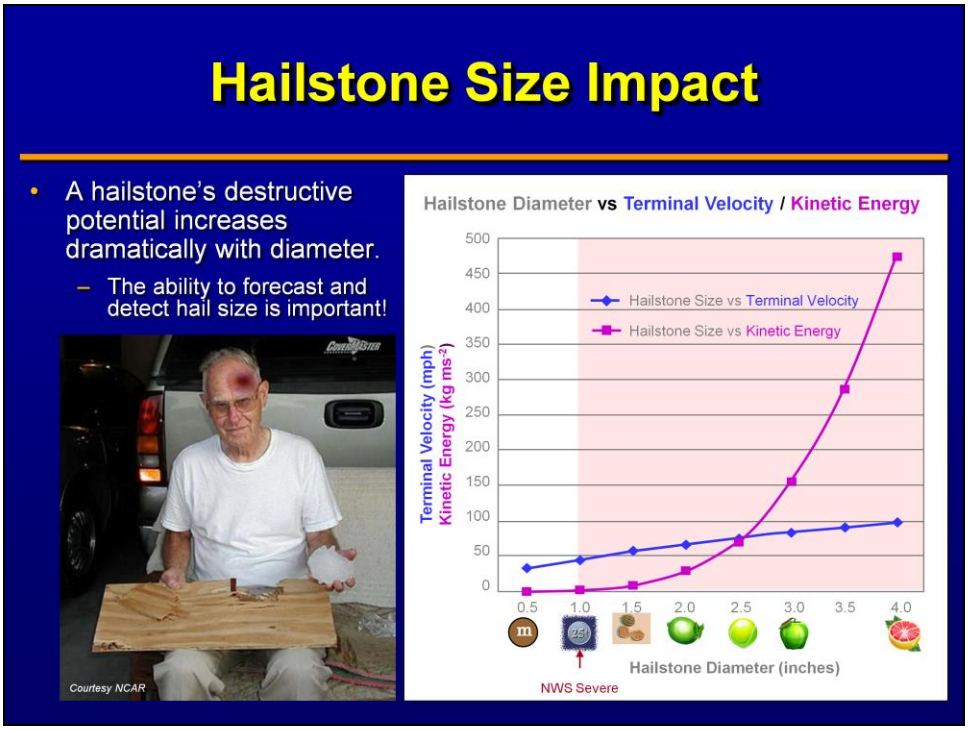
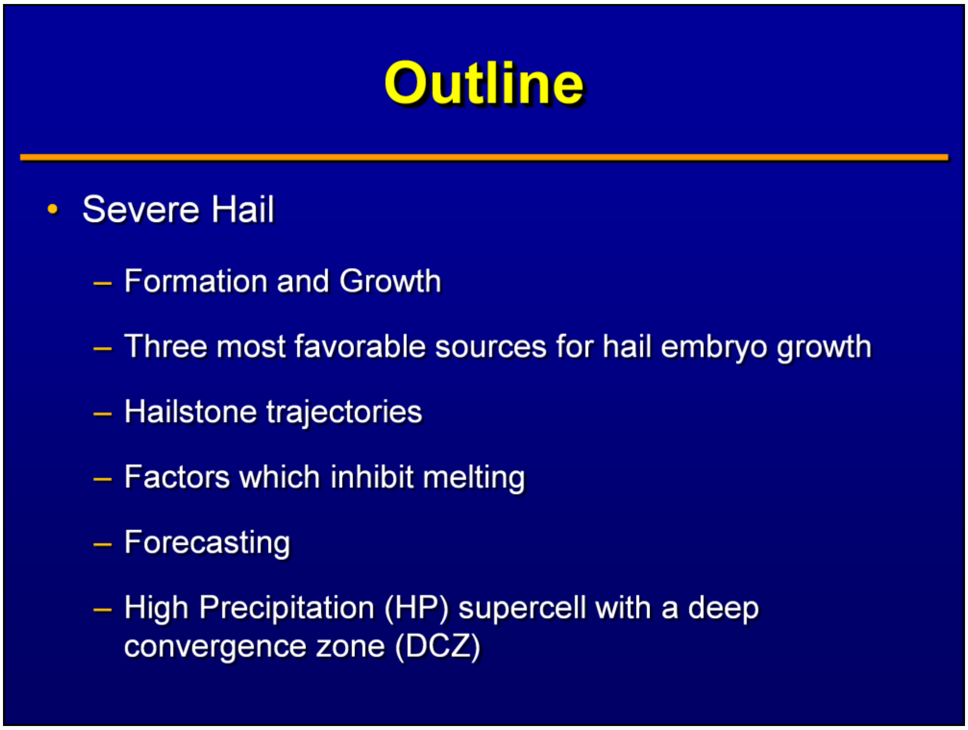


A hailstone's size plays a critical role in its destructive potential. As you can see from this chart, a hailstone's kinetic energy (purple line) increases dramatically with its diameter. That's why the ability to forecast hail size in the warning environment is important. It can be the difference between small hail with little impact and severe or even giant hail with tremendous impact on both life and property.

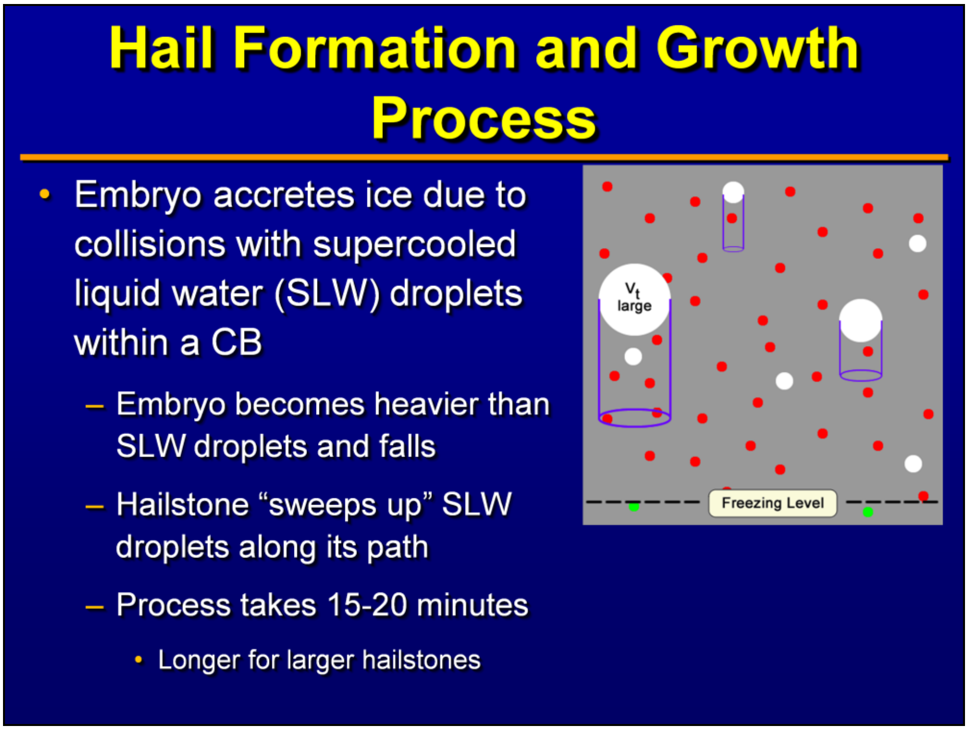


In this lesson we will discuss severe hail, including: Formation and growth, the three most favorable sources for hail embryo growth, characteristics of hailstone trajectories, factors which inhibit hailstone melting, forecasting, and the high precipitation (HP) supercell with a deep convergence zone (DCZ). This last storm type is quite rare, but especially devastating for those in its path.

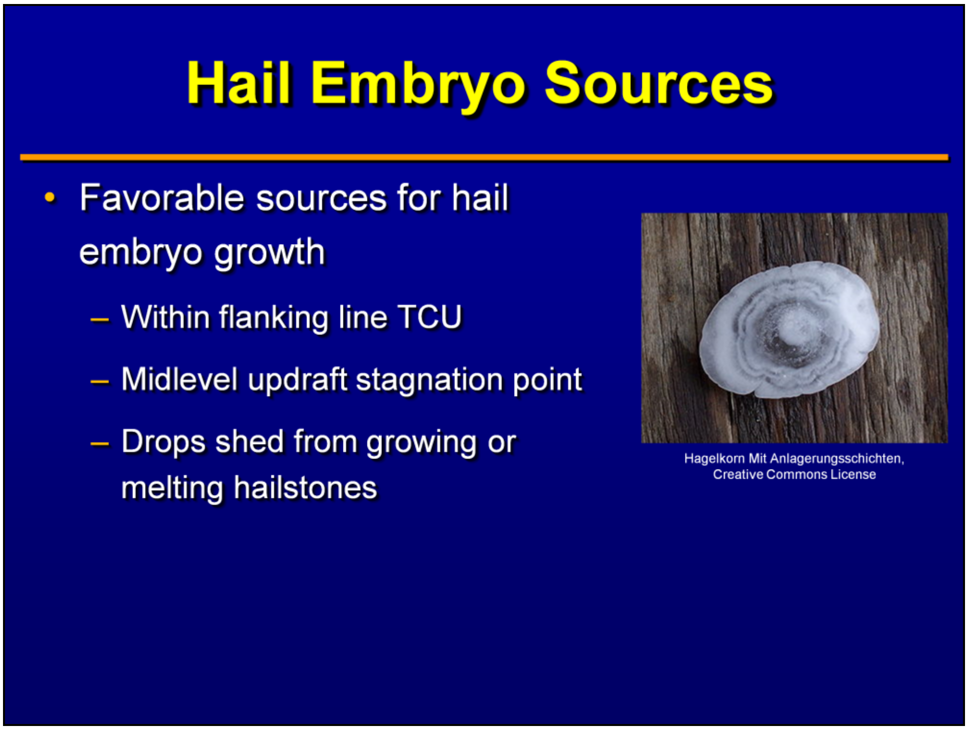
Learning Objectives

1. Identify the three most favorable sources for hail embryo growth.
2. Identify a characteristic of a hailstone trajectories and its relationship to hailstone size.
3. Given a list of factors, identify which one is most important for determining the proportional amount of melting a hailstone will undergo once it falls below the melting level.
4. Given a list of environmental ingredients, identify which one is most favorable for severe hail
5. Identify the role of shear and midlevel rotation on updraft strength and hail threat.
6. Identify a characteristic of the high precipitation (HP) supercell with a deep convergence zone (DCZ).

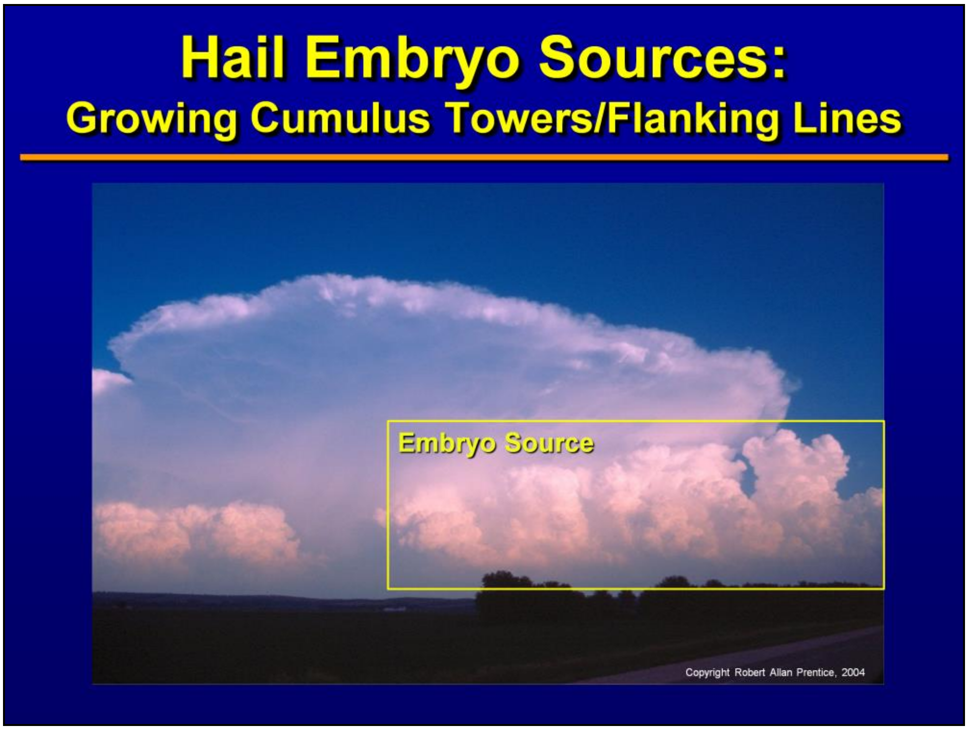
Here are the learning objectives. Please take a moment to read them.



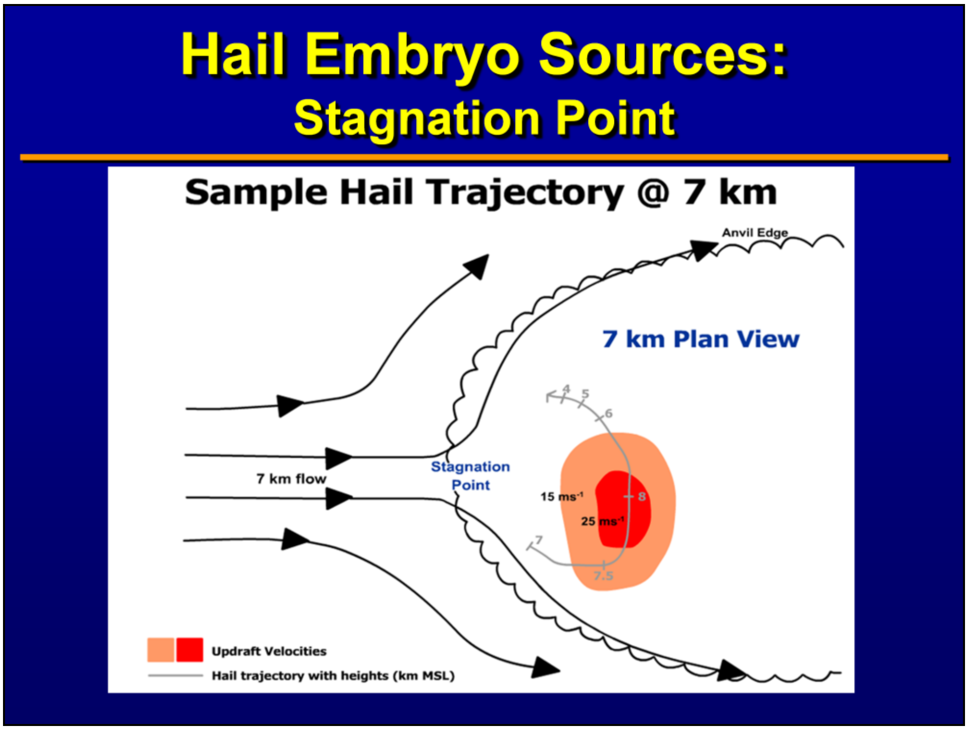
Hail formation requires an embryo to accrete ice due to collisions with supercooled liquid water (SLW) droplets within a cumulonimbus cloud. As the embryo grows it, becomes larger and heavier than the surrounding SLW droplets and falls (relative to the supercooled droplets). The difference in fall velocities between the hailstone and the SLW droplets leads to growth as the stone “sweeps up” droplets along its path. The process takes at least 15-20 minutes, longer for larger hailstones.



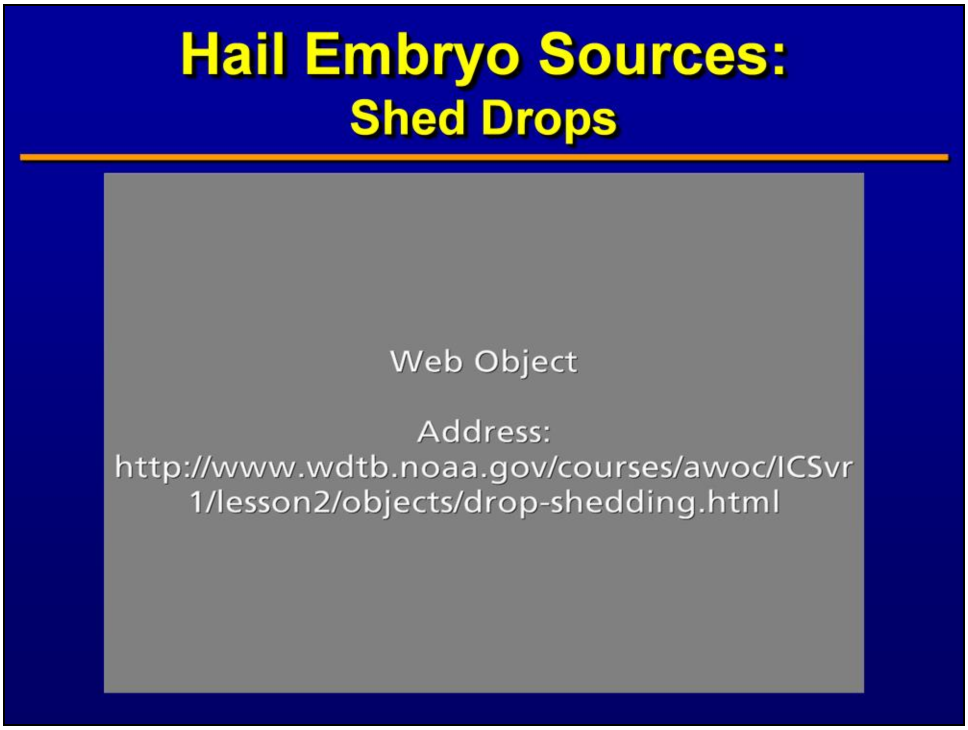
A thunderstorm can possess many different hail embryo sources, all of which can operate simultaneously, but we are going to focus on**<advance>** the three most favorable sources for embryo growth. **<advance>**The first is within developing cumulus towers on the flanks of the parent storm or within the newer updrafts of a multicell storm. **<advance>**The second is near the stagnation point in the midlevels of an intense updraft. **<advance>**And the third source is from drops shed from growing or melting hail. The first two are primary hail embryo sources, while the last one is a secondary source; secondary because hail already has to be within the storm.



Growing cumulus towers and flanking lines near the main updraft of the parent storm provide an ideal incubator for young hail embryos because their updraft velocities are not too strong which allows the embryos to grow to appreciable size before they are advected downwind into the main updraft of the parent storm, where they can then grow into hailstones.

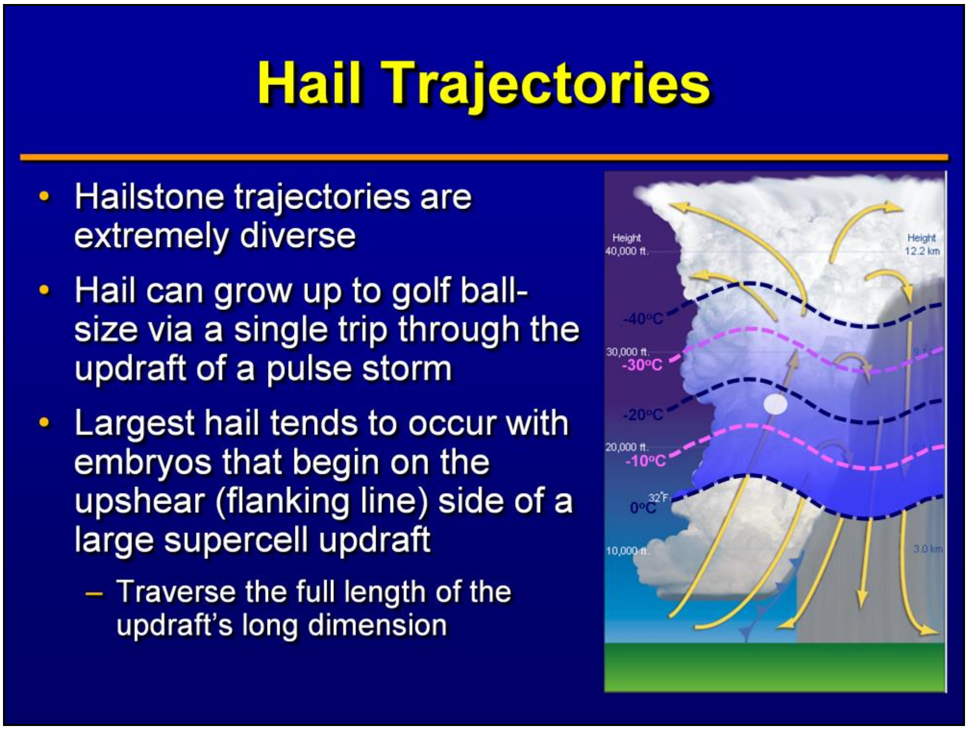


The stagnation point which is found in the midlevels on the upwind-side of an intense updraft is an important source for hail embryo growth. The stagnation point develops because the updraft behaves like an obstacle to the flow, resulting in a dynamically-induced high pressure on the upwind side of the updraft and a region of little or no horizontal flow which occurs where the midlevel flow splits and is diverted around the updraft. Realize that the updraft is porous; that is, it isn't a rigid obstacle to the flow, but rather it diverts a certain percentage of the mid-level flow. Some of the flow still enters and mixes with the updraft. The stagnation point is important for embryo growth because the edges of the main updraft are a region where graupel particles and ice crystals can reside in the hail growth zone long enough to grow into hailstones.



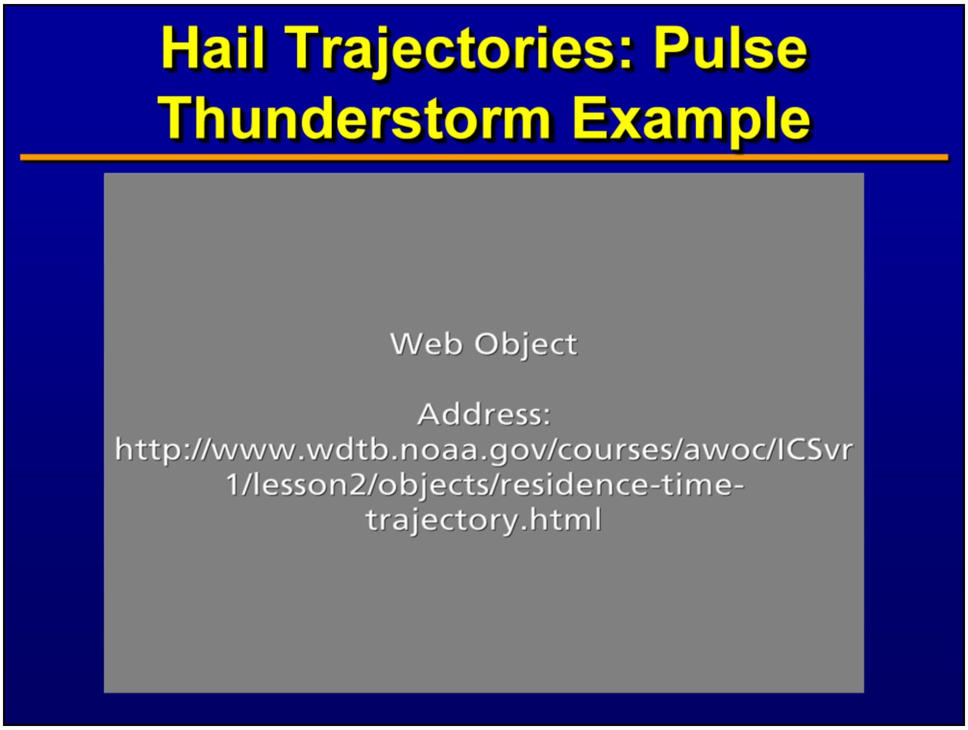
Hailstones greater than 9 mm in diameter have been found to shed liquid drops during both the wet growth and melting processes. These shed drops can then become hail embryos within the supercooled water region of an updraft. Dual-pol radar allows for the detection of drop-shedding regions.

This Flash animation demonstrates how drops are shed from a melting hailstone. Of course, during the melting process drops must be lofted back into the supercooled water region to grow into hailstones.



Recall that a hailstone's size is heavily dependent on its residence time within the most efficient hail growth zone of supercooled water between -10° to -30°C. Strong, wide, persistent updrafts and storm relative winds which aren't too strong are most favorable because they allow a hailstone's terminal velocity to be balanced by the updraft for an extended time in the hail growth zone. Thus, the importance of determining which hailstone trajectories maximize residence time in the hail growth zone is obvious. Problem is, **<advance>**hailstone trajectories have been found to be extremely diverse within convective storms and many different trajectories can occur simultaneously within the same storm. The diversity of the trajectories becomes even more complicated when the storm size, updraft strength, and wind shear increase.

<advance>A hailstone can grow up to the size of about a golf ball via a <u>single trip</u> through the updraft of a pulse thunderstorm (Knight and Knight 2001), but larger sizes require trajectories that recycle the hailstone. An example of this occurs in a multicell thunderstorm when a newer updraft ingests hail fall at its base from an older updraft. A supercell thunderstorm allows for numerous recycling trajectories, but the bulk of the trajectory studies to date have found relatively simple paths through or around the main updraft. **<advance>**The largest hailstones tend to occur with embryos that begin on the upshear (flanking line) side of a large supercell updraft and are then able to experience the longest residence times in the hail growth zone **<advance>**by traversing the full length of the updraft's long dimension.

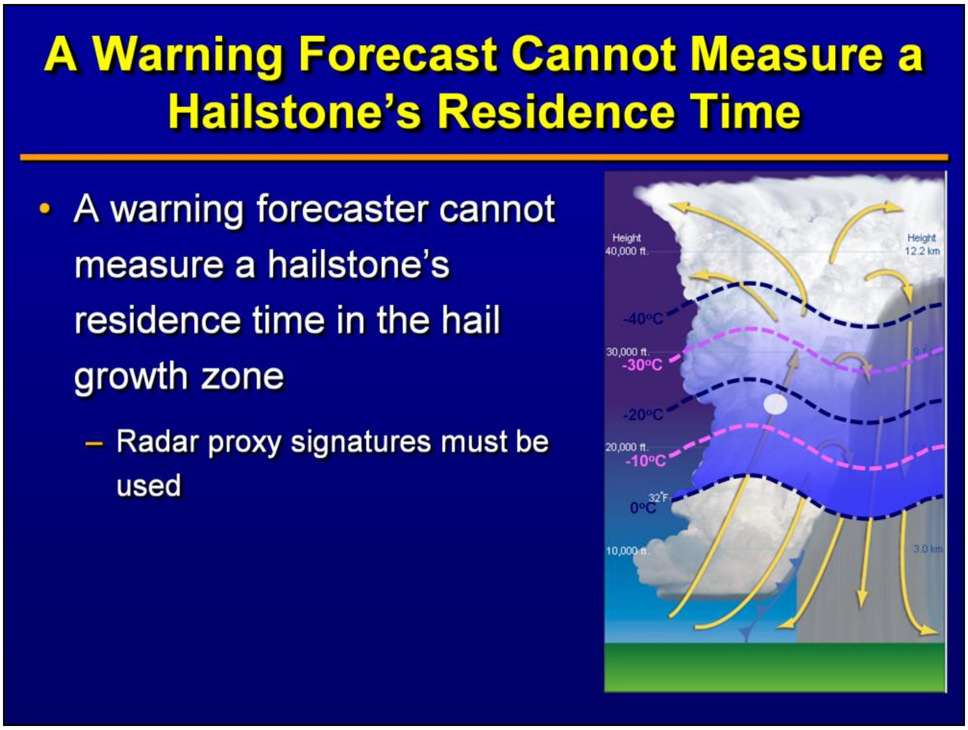


Let's graphically explain what we mean by residence time. In this first image, the color filled isopleths represent updraft velocities in meters per second, the gray dotted isopleths are radar reflectivities in dBZ, and the thick, blue, horizontal, dashed lines are isotherms in degrees Celsius.

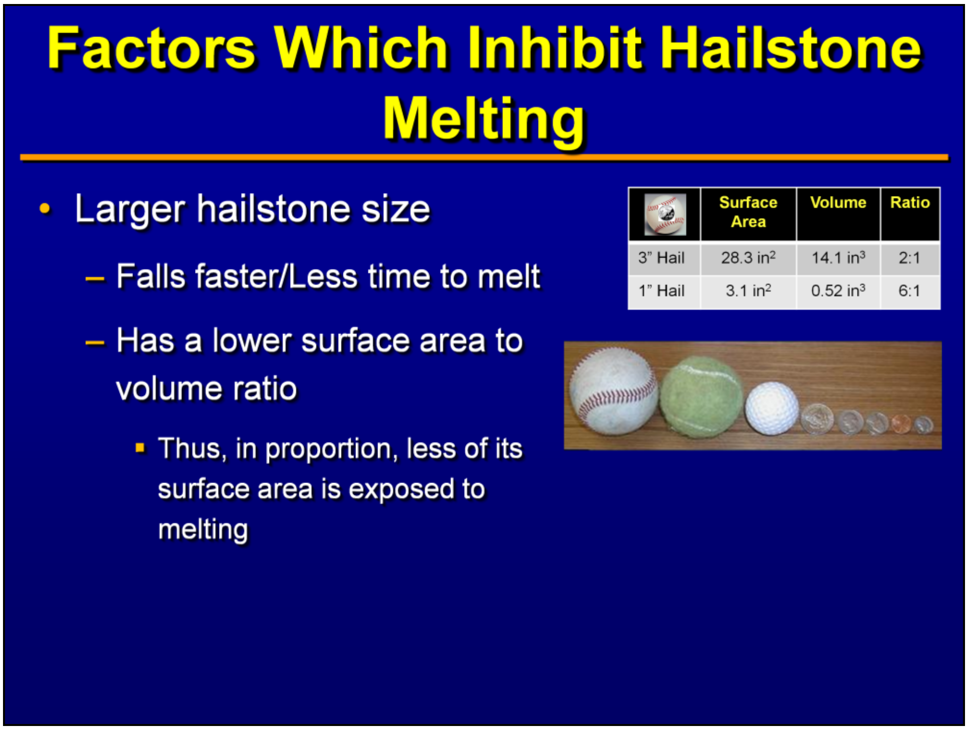
Let's begin with a forward-sheared updraft and a graupel particle which originates from the back-sheared anvil. In this highly simplified two-dimensional model there is horizontal flow across the updraft within which the graupel particle is being advected. As the graupel particle enters the updraft, its terminal velocity is less than that of the updraft velocities it encounters and so it is lofted into the updraft. When the graupel particle enters the region of supercooled water it grows into a hailstone. This growth is most efficient in the hail growth zone between -10° to -30°C. Eventually, the stone's terminal velocity exceeds updraft velocity and the hailstone falls to the surface.

This is an example of a supercell with a trajectory which recycles the hailstone so it can grow to a significant size. The color filled isopleths represent updraft velocities in meters per second and the gray dotted isopleths are radar reflectivities in dBZ.

Notice the particle never rises through the core of the updraft because that is typically precipitation-free as we see in the bounded weak echo region (BWER) here.

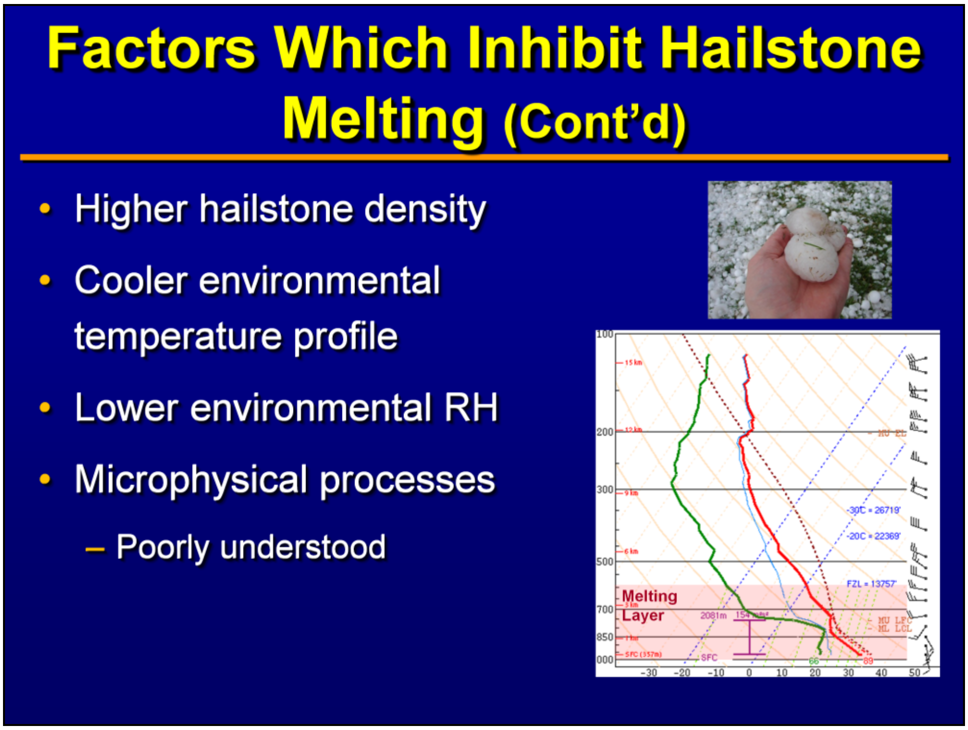


Beware that an operational warning forecaster cannot measure a hailstone's residence time in the hail growth zone. It's difficult to estimate updraft strength, let alone perform a real-time trajectory analysis. Thus, **<advance>**WSR-88D proxy signatures must be used to detect severe hail. Recall these include: High reflectivities (including 60dBZ above -20°C), three-body scatter spike (TBSS), weak echo region (WER), bounded weak echo region (BWER), mesocyclone, and strong storm-top divergence.



It's important to estimate the amount of melting a hailstone will undergo once it falls below the freezing level and into the melting layer. Many factors influence this, the most important of which is hailstone size. All other factors being equal, **<advance>**a larger hailstone melts proportionately less than a smaller hailstone for two reasons: First, a**<advance>** larger hailstone has a faster terminal velocity and spends less time in the melting layer before reaching the surface. For example, a 3-inch hailstone may only take 2 minutes or less to reach the surface, while a smaller stone may take at least twice as long.

The second reason is **<advance>**surface area versus volume ratio. Surface area identifies how much of a hailstone is exposed to melting, while volume identifies how much of its potential water can be melted. A hailstone's surface area is proportional to its radius, squared, while its volume is proportional to its radius, cubed. **<advance>**Thus, a larger hailstone has a proportionately smaller surface area exposed to air and, proportionately, melts slower. For example, a 3-inch hailstone has a surface area of 28.3 in^2 and a volume of 14.1 in^3 while a 1 inch hailstone has a surface area of 3.1 in^2 and a volume of 0.52 in^3. The ratio is 2:1 for the 3-inch hailstone, but 6:1 for the 1-inch hailstone, and thus, proportionately the larger stone melts much less.

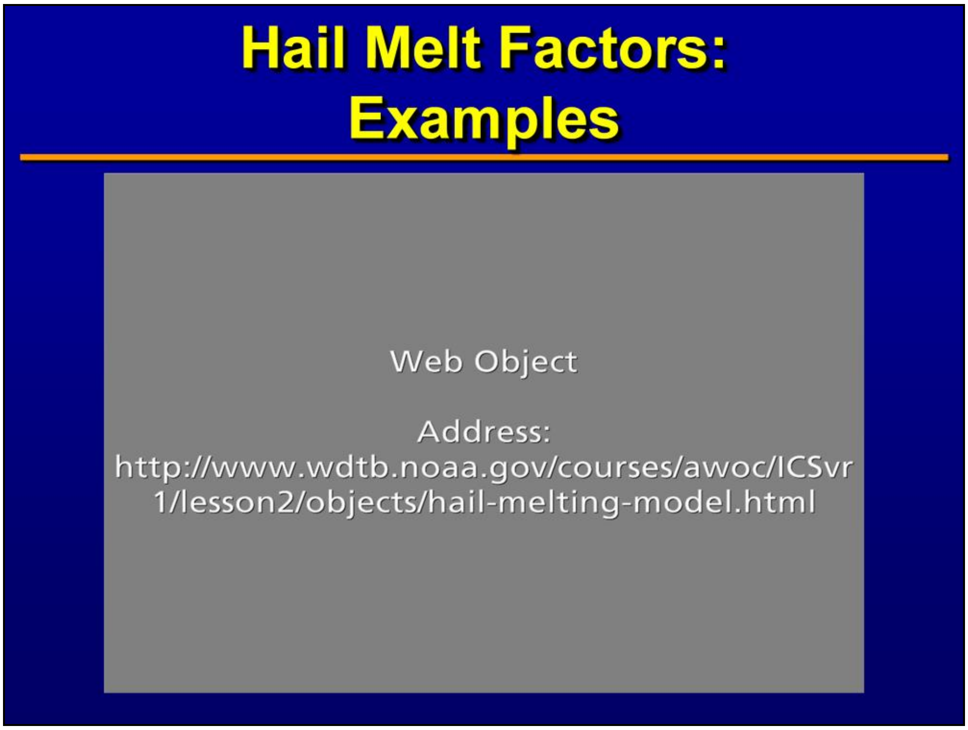


A few other factors play a role as well, **<advance>**including hailstone density. Higher density hail melts much less effectively than lower density hail which is typically graupel cores.

<advance>Environmental temperature profile is directly related to hailstone melting. A lower freezing level with colder temperatures below it intuitively favors less melting as heat transfer from the atmosphere to the hailstone is smaller in a colder environment. Conversely, a higher freezing level with warmer temperatures below it enhances melting.

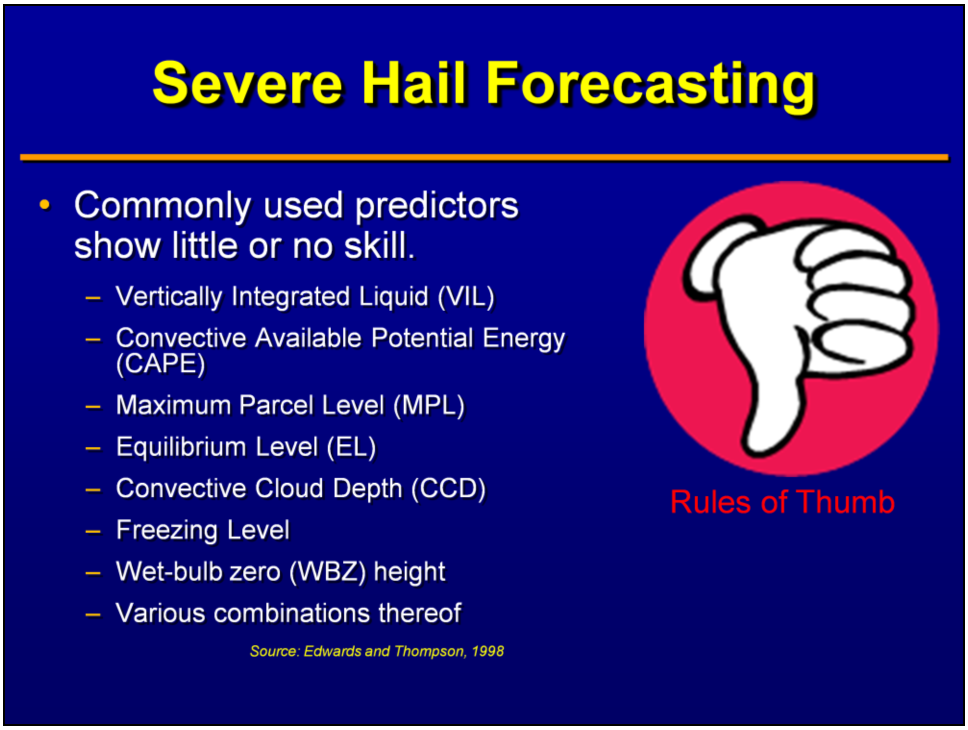
<advance>Environmental relative humidity is directly related to hailstone melting. Lower environmental relative humidity decreases hailstone melting because it delays the onset of melting by providing favorable conditions for the hailstone surface to remain dry. In melting layers with 50% or less relative humidity, melting has been found to proceed when the stone reaches air with a temperature of +5 ^{o}C, obviously diminishing the amount of time the hail falls through the melting layer. Additionally, lower relative humidity hinders melting even if the stone is coated in water, since the layer of water is more likely to evaporate off the surface, cooling both the hailstone and the surrounding environment via the latent heat of vaporization, further slowing the melting process.

<advance>Finally, microphysical differences between the makeup of all the stones in a hail fall can also influence melting, **<advance>**although these differences have not been studied nor can they be measured at this time. Some of these differences are shape of the hailstone, hailstone size spectrum within a particular hail fall, and direct influences of surface hailstone heat transfer, among others.



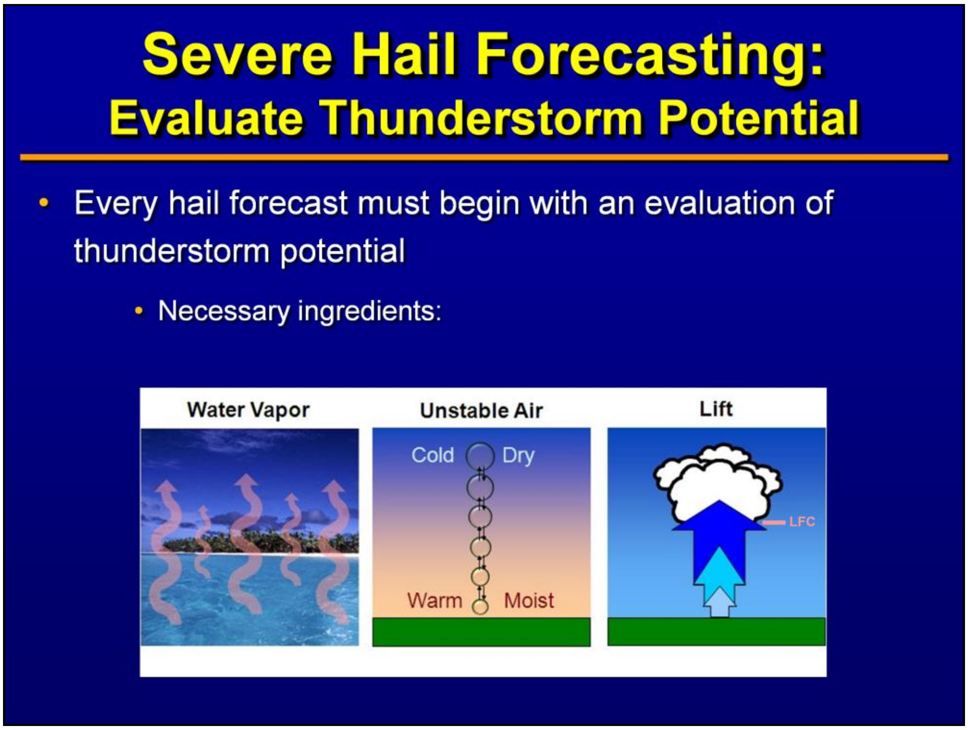
Now it’s your turn to investigate the various melting parameters we’ve discussed. This Flash animation is based on a AMS Journal Article by Rasmussen and Heymsfield from 1987. You’re going to find that lower hailstone density, higher relative humidity, and warmer temperature favor melting, but larger hailstones don’t proportionately melt much regardless of these factors.

However, remember back to the hailstone size versus kinetic energy chart at the beginning of this lesson. Melting a large hailstone even by a little can noticeably reduce its destructive power.

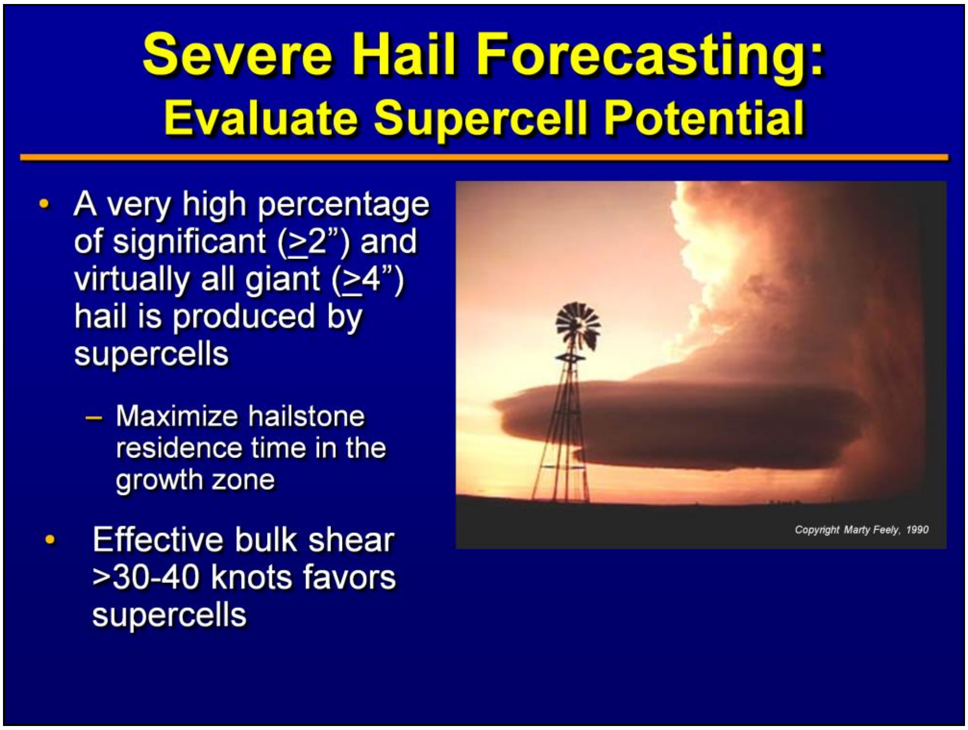


Hail forecasting is an immature science. On a nationwide basis, **<advance>**commonly used hail predictors showed little or no skill in predicting hail size. These include: Vertically Integrated Liquid (VIL), Convective Available Potential Energy (CAPE), Maximum Parcel Level (MPL), Equilibrium Level (EL), Convective Cloud Depth (CCD), Freezing Level, Wet-bulb zero (WBZ) height, and various combinations thereof (*Source: Edwards and Thompson, 1998).*

So let’s start with the basics and emphasize what we do know.



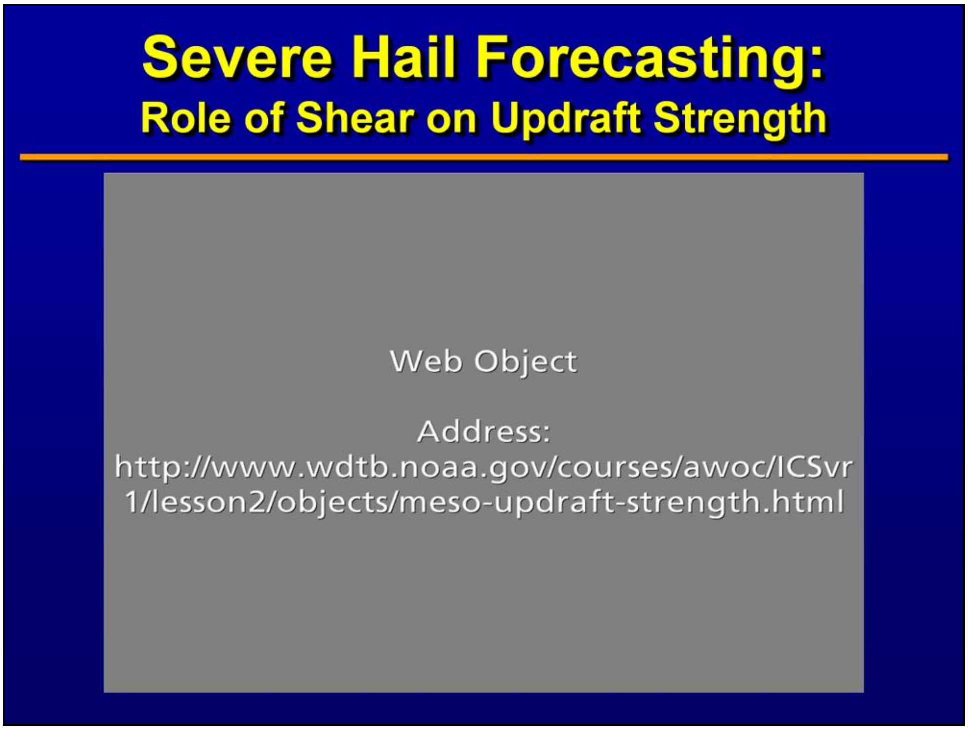
Hail is always produced by convective clouds, nearly always cumulonimbus. Thus, **<advance>**every hail forecast must begin with an evaluation of thunderstorm potential. Recall from basic meteorology that **<advance>**all thunderstorms require three ingredients: Sufficient water vapor (typically measured as dewpoint), to produce unstable air (almost always conditional instability), and a lifting mechanism to lift the air parcels to their level of free convection (LFC) to release the convective instability. The lift can come from many sources including: Frictional convergence around surface lows and troughs, frontogenesis with fronts, drylines, upslope flow, outflow boundaries from previous storms, and local winds such as sea breeze, lake breeze, and valley breeze circulations.



A mesocyclone, the defining characteristic of a supercell, is a strong indicator of severe hail. In fact, **<advance>**a very high percentage of significant (≥2-inch diameter) and virtually all giant (≥4”) hail events are produced by supercells. This is because supercells possess strong, persistent updrafts due to dynamic pressure perturbations **<advance>**which help maximize hailstone residence time in the preferred -10°C to -30°C hail growth zone. Thus, given the potential for thunderstorms, every hail forecaster should evaluate supercell potential.

Recall that bulk shear through the lower half of a storm’s depth (i.e., effective bulk shear) has been found to be an effective discriminator between ordinary and supercell storm types. **<advance>**Effective bulk shear greater than 30-40 knots favors supercells and, thus, is an important ingredient for significant (≥ 2-inch diameter) hail.

Let’s talk about dynamic pressure perturbation in more detail.



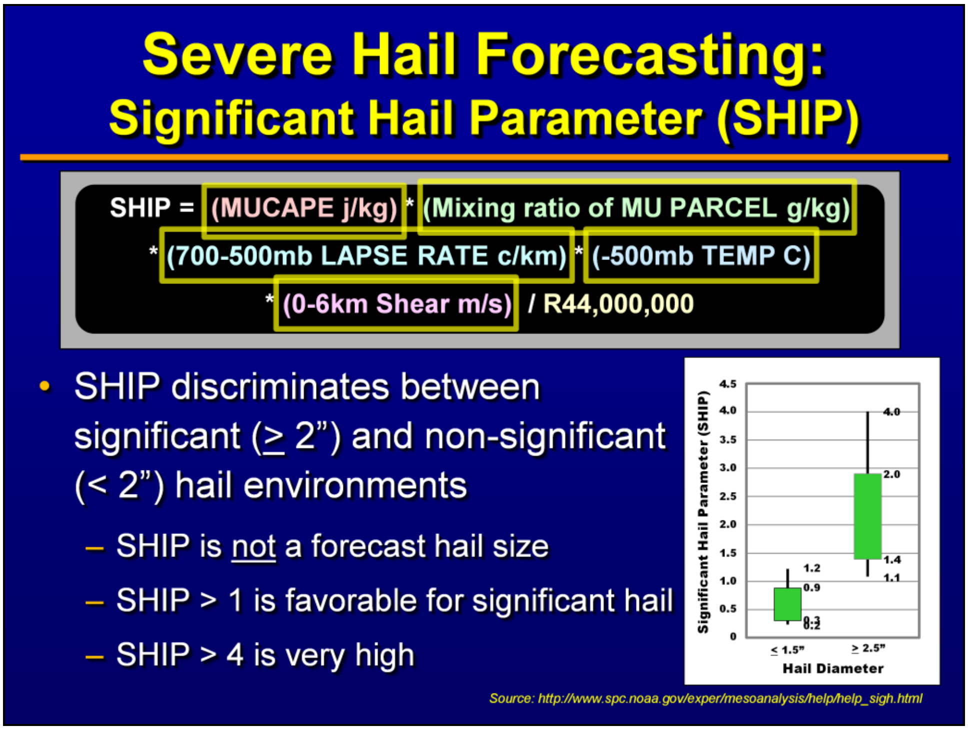
Recall from the lesson on supercells, that vertical wind shear produces horizontal vorticity that can tilted into the vertical within a strong updraft. This now vertically-oriented vorticity is associated with updraft rotation and is typically strongest in the mid-levels of the updraft.

Focusing on the left part of this graphic, regardless of the direction of spin of the rotation, whether cyclonic or anti-cyclonic, centrifugal force is associated with the rotation. The stronger the rotation, the stronger the centrifugal force. Strongly rotating updrafts are identified as mesocyclones on radar.

To keep the forces balanced, an opposing pressure gradient force must be present. Again, regardless of the direction of spin, whether cyclonic or anti-cyclonic, dynamically-induced low pressure develops in the mid-levels of the updraft which creates an inward directed pressure gradient force.

Focusing now on the right part of the graphic, this low pressure leads to an upward directed pressure gradient force below the circulation, which intensifies the upward vertical motion. It has been shown mathematically that the dynamically induced (via mid-level rotation) contribution towards total updraft velocity can be as large as the contribution due to buoyancy, effectively “doubling the CAPE.”

Stronger updrafts have the ability to support larger hailstones. Thunderstorm updrafts which contain strong, persistent rotation (i.e., a mesocyclone) are stronger than buoyancy considerations alone would suggest and possess a higher threat of severe hail (all other environmental factors being equal). Thus, a mesocyclone, the defining characteristic of a supercell, is a strong indicator of severe hail.



As previously stated, many hail forecast predictors commonly used in the past have later been proven to have little or no skill. However, one parameter which has shown operational utility on a national scale is the Significant Hail Parameter (SHIP).

SHIP was developed at the Storm Prediction Center using a large database of surface-modified, observed severe hail proximity soundings. It is based on five parameters and is meant to **<advance>**delineate between significant (≥ 2" diameter) and non-significant (< 2" diameter) hail environments. Those parameters are: **<advance>**Most unstable CAPE (MUCAPE), **<advance>**mixing ratio of the most unstable parcel, **<advance>**the 700-500 millibar lapse rate, the 500 millibar temperature, and **<advance>**the 0-6km shear.

It is important to emphasize that**<advance>** **SHIP is not a forecast of a specific hail size.** **<advance>**Values greater than 1 indicate a favorable environment for significant hail. **<advance>**Values greater than 4 are considered very high. In practice, values 1.5-2.0 or higher will typically be present when significant hail is going to be reported.

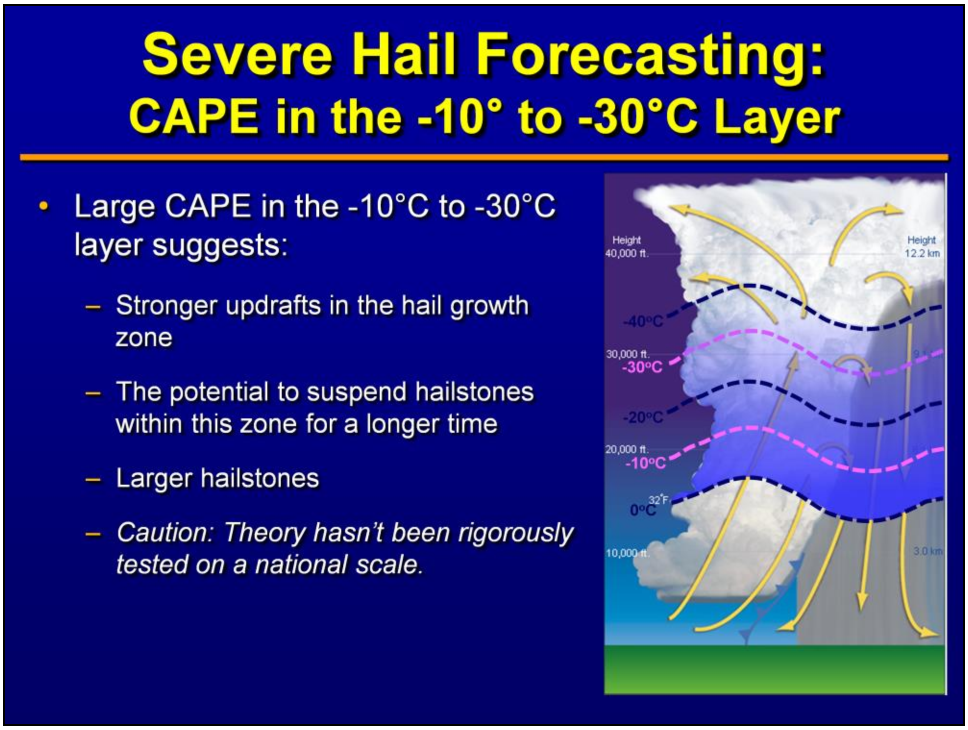
Recall that supercells produce a high percentage of significant hail events. Thus, it's not surprising that most unstable CAPE and 0-6 km bulk shear are two of the ingredients.

Note: The 10th, 25th, 75th, and 90th percentiles are shown for each box and whiskers subset.

Severe Hail Forecasting:
SHIP Sources

- SHIP is available at:
  - SPC Mesoscale Analysis Pages
  - SPC Observed Sounding Analysis
  - AWIPS-2 NSHARP

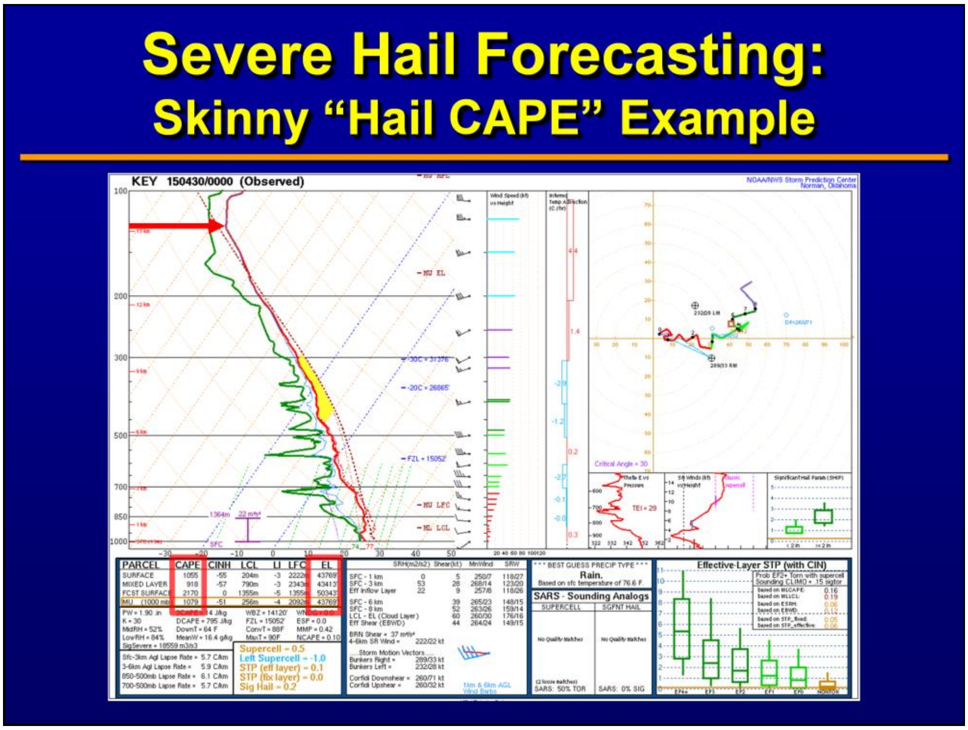
SHIP is available at: **<advance>**The SPC Mesoscale Analysis Pages, **<advance>**the SPC Observed Sounding Analysis web page, and **<advance>**on AWIPS-2 NSHARP.



Hailstone formation requires an embryo (ice crystal, graupel, rain drop, etc.) to accumulate ice as it traverses the supercooled water region within a cumulonimbus updraft. Research studies have concluded that **the most efficient hailstone growth occurs within the -10^{o} to -30^{o}C temperature range. Thus, a hailstone's size is dependent on its residence time within its parent thunderstorm's "hail growth zone."**

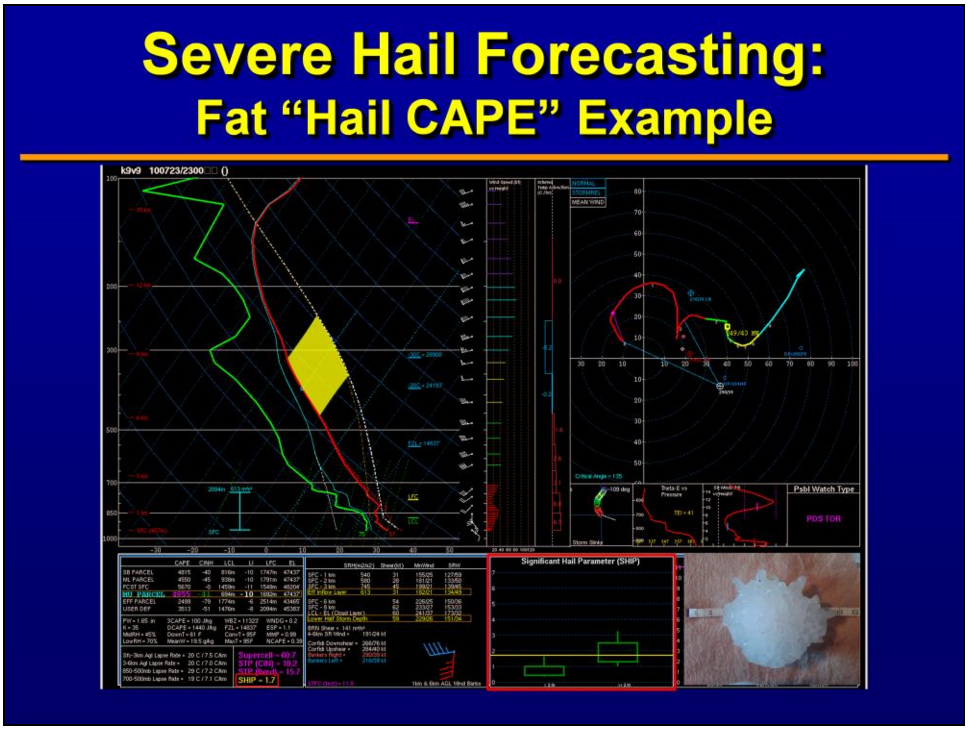
A factor thought to influence this residence time is CAPE, particularly CAPE in the hail growth zone. All other factors being equal, **<advance>**higher CAPE in the -10^{o} to -30^{o}C layer indicate **<advance>**stronger thunderstorm updrafts within the hail growth zone and **<advance>**the potential to suspend hailstones within this zone for a longer time, leading to **<advance>**larger hail stones.

<advance>Beware that CAPE in the hail growth zone is just a concept based on a model which uses simplified hail growth trajectories and hasn't been rigorously tested as a forecast parameter on a national scale. Let's show a few examples.

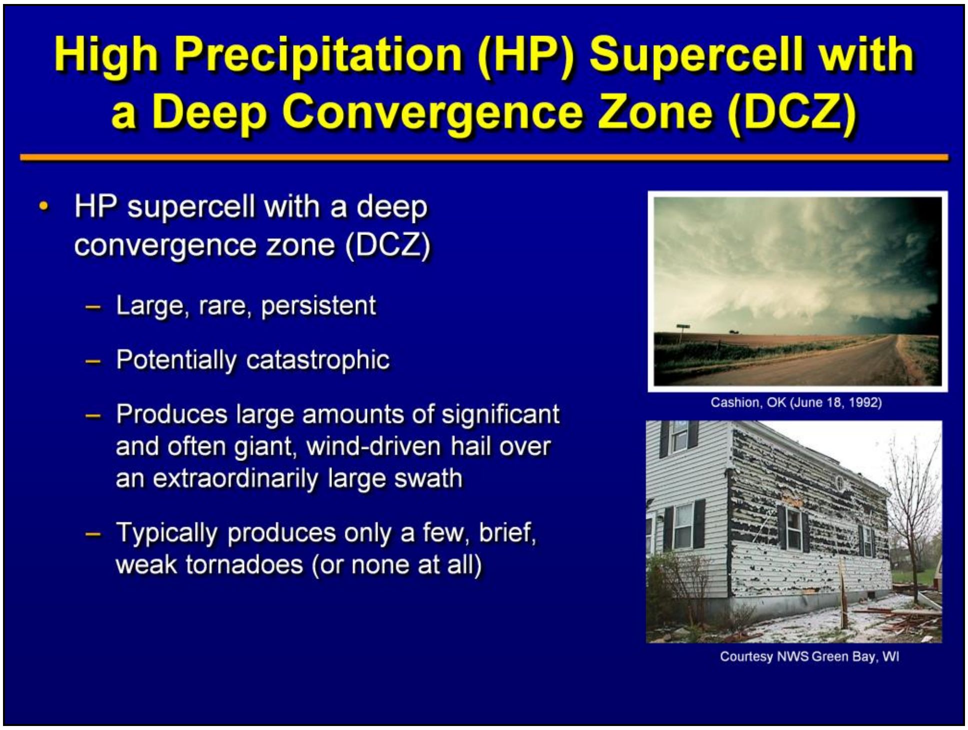


This is an observed sounding from Key West, Florida (KKEY) at 00Z on April 30, 2015. Note it has **<advance>**substantial CAPE; around 1,000 J/kg of SBCAPE, MLCAPE, and MUCAPE. The **<advance>**lifted parcel equilibrium level of ~43,000 feet is quite high. However, it’s in a tropical environment as denoted by the shallow, nearly moist adiabatic lapse rates and **<advance>**high tropopause around 130 mb (15 km). The 1,000 J/kg of CAPE extends through a large vertical depth and the profile is “skinny.” **<advance>**CAPE in the preferred -10ºC to -30ºC hail growth zone was low; only about 200 J/kg according to the SPC Mesoscale Analysis (not shown). Consequently, even with significant CAPE and vertical wind shear, there were no hail reports with these thunderstorms.

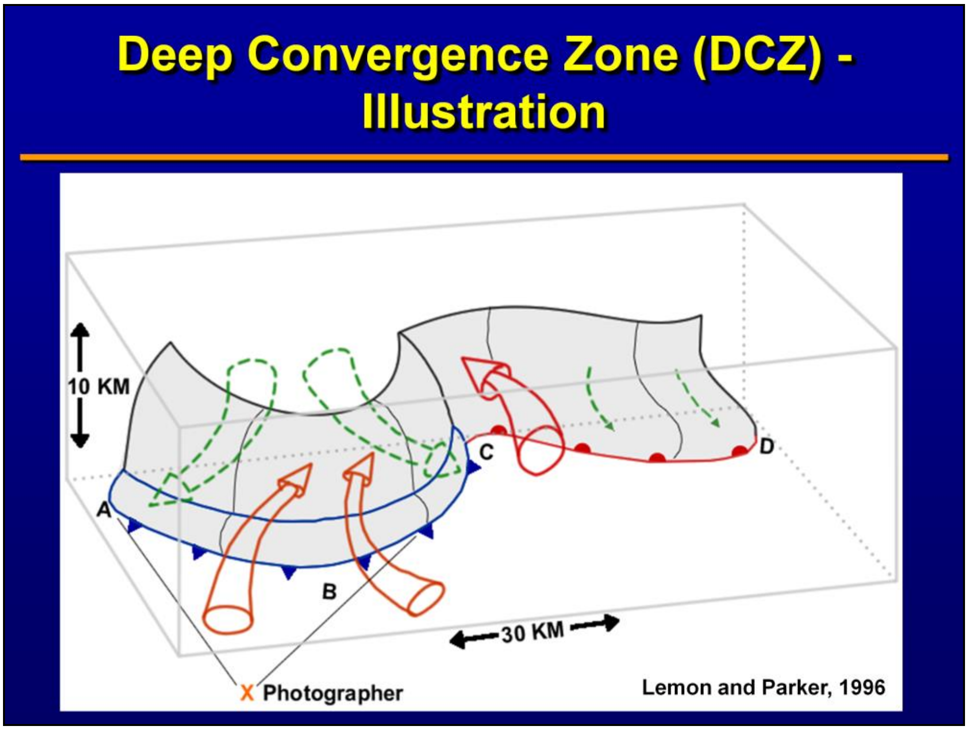
Bear in mind, supercells sometimes have the capability of producing severe hail even with a “skinny” CAPE profile.



This is a RAP model analysis sounding for Chamberlain, South Dakota (K9V9) at 23Z on July 23, 2010. **<advance>**CAPE in the preferred -10ºC to -30ºC hail growth zone was very large, about 900 J/kg according to the SPC Mesoscale Analysis (not shown). Around this time, a supercell 50 miles to the west at Vivian, South Dakota produced an 8-inch diameter hailstone, which set a U.S. record. **<advance>**Note that SHIP is “only” 1.7, which suggests greater than 2-inch diameter hail, but not necessarily 8-inch diameter hail!

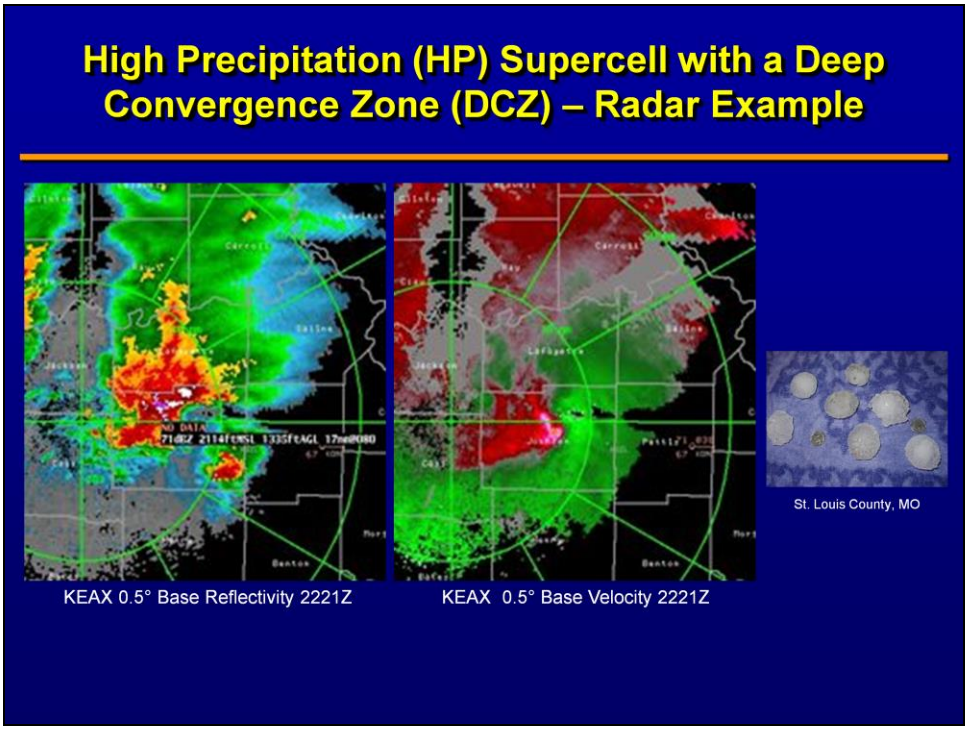


One final topic I'd like to discuss is **<advance>**the high precipitation (HP) supercell with a deep convergence zone (DCZ). **<advance>**This is a large, rare, persistent, **<advance>**potentially catastrophic thunderstorm which **<advance>**produces large amounts of significant (≥ 2-inch diameter) and sometimes giant (≥ 4-inch diameter), wind driven hail over an extraordinarily large swath. **<advance>**It typically produces only a few, weak, brief tornadoes or none at all. The slang term for this storm is "hurricane hailer."



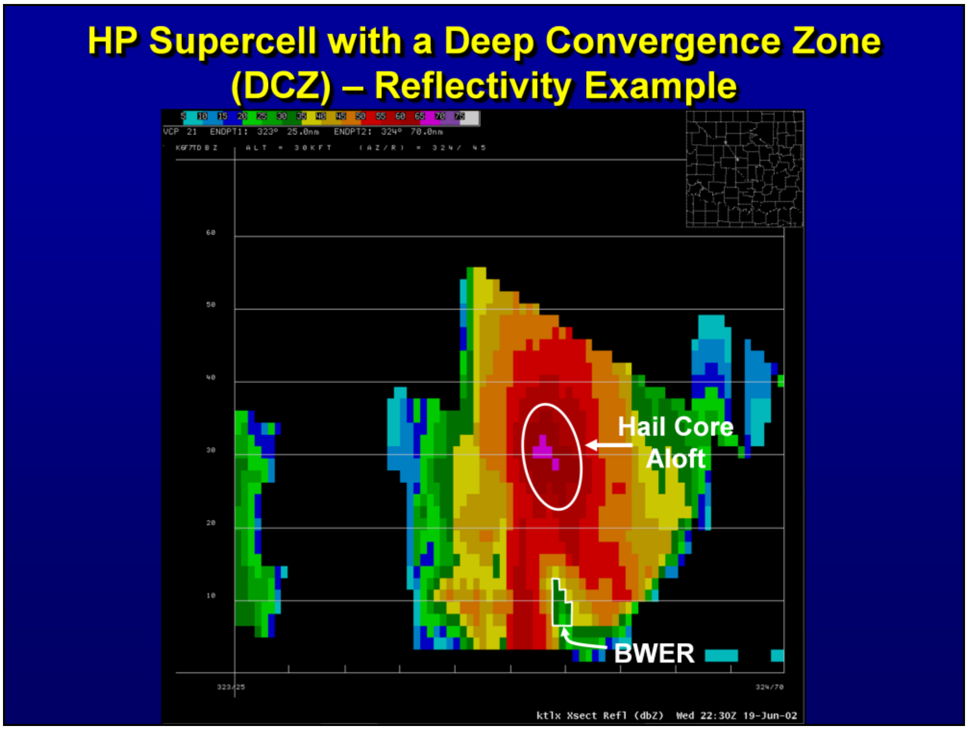
This HP supercell's most prominent characteristic is a deep zone of convergence (DCZ) which is a narrow zone of high shear and turbulence found along the leading edge of both the rear and forward flank gust fronts and sloping vertically though midlevels of the storm (~10 km/ 33 kft). The DCZ behaves like a "fluid wall" separating the major storm drafts; dry, potentially cold mid-level inflow feeding downdraft on one side and very warm, moist, low-level inflow feeding the updraft on the other side. Air stream mixing is effectively confined to this narrow zone which shields the supercell updraft from destructive mixing effects and allows the undiluted updraft to approach parcel theory values supportive of significant and often giant hail. The storm contains a very wide region of updraft; not necessarily one single updraft, but many updrafts which collectively form an extensive hail growth zone. The DCZ accounts for the sheer size of the hail cores as revealed by high reflectivities along both the rear and forward flanks.

This illustration of the deep convergence zone (shaded region) associated with the Lahoma HP supercell of August 17, 1991, is adapted and updated from an image first published in Lemon and Parker (1996). Arrows indicate storm relative flow while dashed arrows indicate, in perspective, flow behind the deep convergence zone surface. Storm motion is out of the illustration, directly towards you. The supercell updraft with a bounded weak echo region (BWER) is located from B to C and the storm summit is in the vicinity of B. The most intense and deep portions of the deep convergence zone are found nearly coincident with the strong reflectivity gradients bordering the weak echo region (WER) and BWER. In the Lahoma supercell, the deep convergence zone passage signaled the greatest wind threat and within 2-5 minutes, the greatest hail threat.

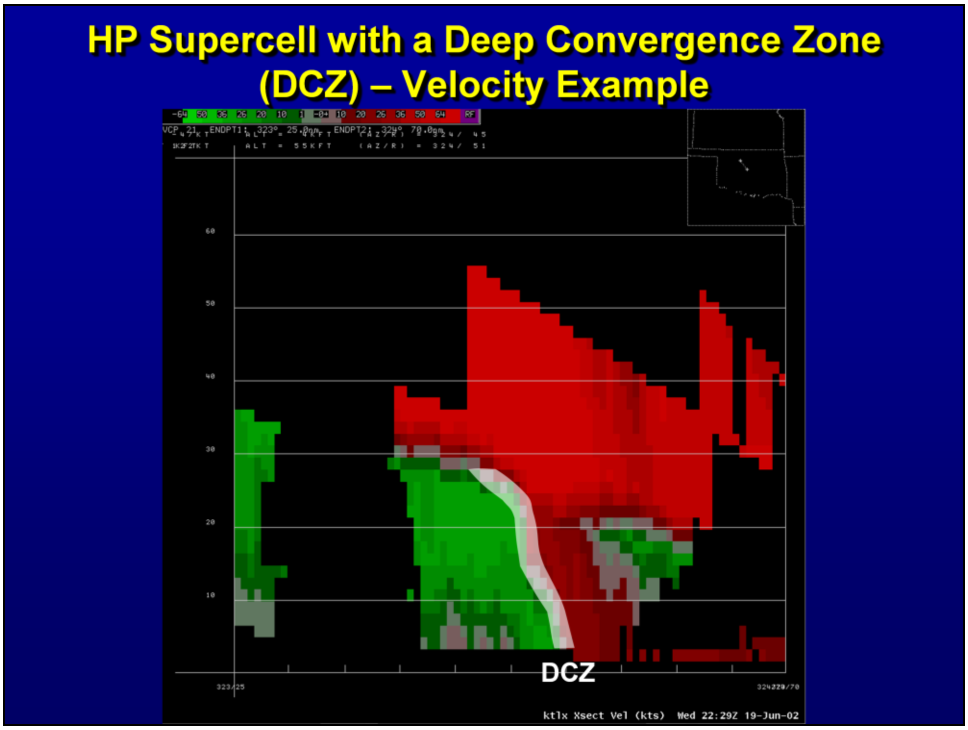


Here is a radar example of an HP supercell with a DCZ on April 10, 2001, as seen from the Kanas City/Pleasant Hill, MO (EAX) WSR-88D. The 0.5 degree base Reflectivity is on the left and the corresponding base velocity is on the right. In reflectivity, we can see a giant core of extreme 70 to 80 dBZ reflectivity within both the forward and rear flank downdrafts. In velocity, we see extreme convergence along the supercell's rear flank which extended upward as a deep convergence zone.

This storm tracked all the way eastward across Missouri along I-70 from Kansas City to Columbia to St. Louis. It produced several weak tornadoes and large amounts of golfball to baseball size hail driven by winds of 60 to 70 mph. It was the costliest hailstorm in U.S. history at the time. In the St. Louis area alone, more than 40,000 insurance claims for vehicles were taken. In Florissant, a suburb with more than 50,000 people, it was estimated that almost every home suffered some type of hail damage.



This is a Base Reflectivity cross section taken through an HP supercell with a DCZ. This image is quite similar to the hail trajectory recycling Flash animation shown earlier. **<advance>**Note the bounded weak echo region and **<advance>**extreme reflectivity hail core suspended above it.



Here is the corresponding Base Velocity cross section. **<advance>**Notice the deep convergence zone (DCZ) extends through a considerable fraction of the supercell's depth.

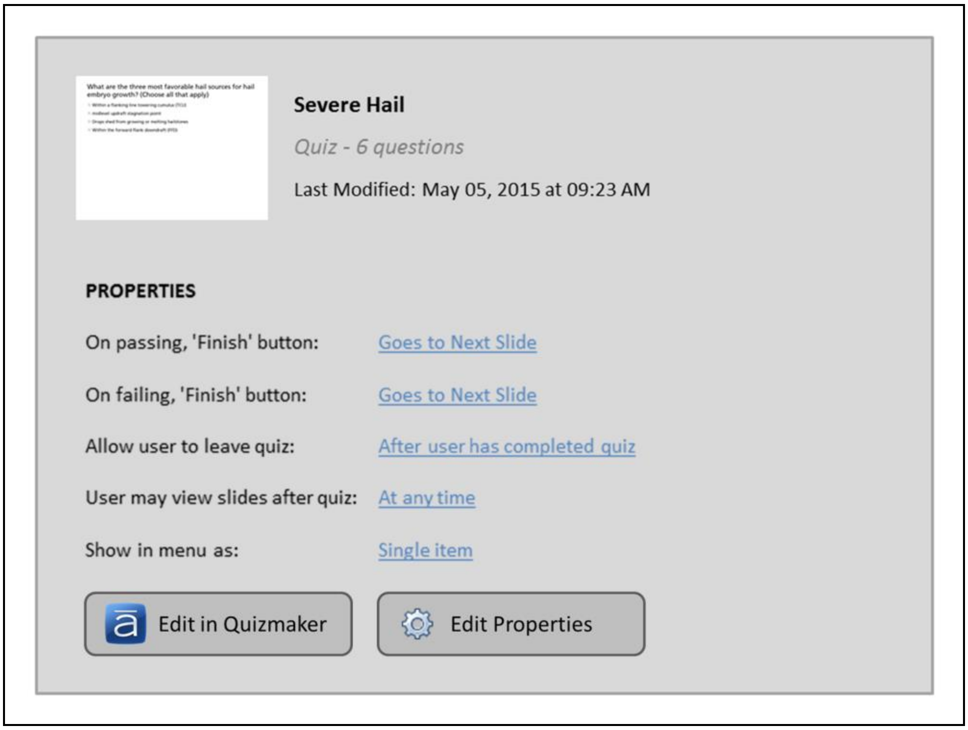
Hail Ingredients Summary

Ingredients Favorable for Larger Hailstone Sizes	
Microphysics	Kinematics
High supercooled liquid water content	Light storm-relative flow though updraft
Wet growth in mixed phase region	Large contiguous updraft of 20-40 m/s (39-78 kt)
Low density growth	Optimal trajectories
Large embryos	Favorable horizontal updraft gradients

Ingredients Favorable for Larger Amounts of Hail	
Microphysics	Kinematics
High embryo concentration	Large contiguous updraft of 20-40 m/s (39-78 kt)
Ample supercooled liquid water content	Flow that injects embryos across a broad updraft front

Here are summaries of microphysical and kinematic ingredients favorable for larger hailstone sizes and larger amounts of hail. The problem with many of these ingredients is they cannot be forecasted or measured operationally. This helps to explain why hail forecasting is so difficult.

Fortunately, radar detection of hail is somewhat easier, especially with the advent of dual-polarization radar. Be sure to review previous WDTD modules for refresher training on this.


Severe Hail
Quiz - 6 questions
Last Modified: May 05, 2015 at 09:23 AM
PROPERTIES
On passing, 'Finish' button:
Goes to Next Slide
On failing, 'Finish' button:
Goes to Next Slide
Allow user to leave quiz:
After user has completed quiz
User may view slides after quiz:
At any time
Show in menu as:
Single item
Edit in Quizmaker
Edit Properties

Click this link for a list of references used in this lesson.